NASA STTR 2015 Phase I Solicitation

Small Business Technology Transfer

Launch Propulsion Systems Topic T1

Launch Propulsion Systems reflects a staged development of critical technologies that include both “pull” technologies that are driven by known short- or long-term agency mission milestones, as well as “push” technologies that generate new performance or mission capabilities over the next 20 to 25 years. While solid and liquid propulsion systems are reaching the theoretical limits of efficiency, they have known operational and cost challenges while continuing to meet critical national needs. Improvements in these launch propulsion systems and their ancillary systems will help maintain the nation’s historic leadership role in space launch capability. Newer technologies like air-breathing launch propulsion, unconventional, and other propulsion technologies and systems, while low in TRL, can radically transform the nation’s space operations and mission capabilities and can keep the nation’s aerospace industrial base on the leading edge of launch technologies.

Sub Topics:

T1.01 Affordable Nano/Micro Launch Propulsion Stages

Lead Center: MSFC

Participating Center(s): GRC, KSC, LaRC

As small satellites have become more capable of performing valuable missions for both government and commercial customers, there has been significant growth in both the quantity and quality of Nano and Micro Satellite missions. Currently these satellites can only be launched affordably as secondary payloads; but the number of these missions has outpaced available ride share opportunities. This limitation makes it difficult for small satellite missions to launch when needed and to attain the desired orbit with an acceptable risk.

A dedicated access to space also allows new and emerging technologies that increase capability and/or decrease costs to be demonstrated and qualified. Additive manufacturing is one example of such a technology. Technologies that are demonstrated and validated at the nano/micro scale can also be robustly infused into large launch vehicles where loads are not as severe.

Low cost, dedicated launch vehicles are required that will robustly meet the nano/micro satellite launch needs. This subtopic solicits technology proposals for propulsion stages of such a launcher. Specifically, the subtopic requests proposals for propulsion design tools and stages for application as booster stages, upper stages or orbit insertion stages. Stage concepts are sought that can be demonstrated within the schedule and budget of a Phase II STTR project with the following goals and constraints:

- Accepted proposals will be limited to stages that are applicable to existing or proposed architectures for orbital launch vehicles.
- A sub-orbital flight test is expected in Phase II. Additionally, the path from the sub-orbital flight test to orbital capability must be clearly defined.
- Demonstrations other than a sub-orbital flight test will be considered. However anything less than a sub-orbital flight test will require the documentation of the explicit path, including test plans and cost data, to an orbital-capable stage.
- Payload capabilities in the 5-50 kg range are targeted.
- Small launch vehicles are targeting total launch costs (fixed, reoccurring and range costs) in the $1-2 million range. Proposed stages should demonstrate costs that fit within this range.
Phase I activities should develop the data necessary to assert with confidence that the proposed technology solution has a clear path to meet the goal an affordable orbital launch vehicle. Phase II activities will include sub-orbital stage flight-testing for verification of functionality as well as substantiation of cost projections for the orbital stage.

In-Space Propulsion Technologies Topic T2
Reserved for future Solicitations.

Sub Topics:
Space Power and Energy Storage Topic T3
Space Power and Energy Storage is divided into four technology areas: power generation, energy storage, power management and distribution, and cross cutting technologies. NASA has many unique needs for space power and energy storage technologies that require special technology solutions due to extreme environmental conditions. These missions would all benefit from advanced technologies that provide more robust power systems with lower mass.

Sub Topics:
T3.01 Energy Harvesting Technology Development

Lead Center: SSC

Participating Center(s): GRC, JSC, KSC

The NRC has identified a NASA Top Technical Challenge as the need to "Increase Available Power". Additionally, a NASA Grand Challenge is "Affordable and Abundant Power" for NASA mission activities. As such, novel energy harvesting technologies are critical toward supporting future power generation systems to begin to meet these challenges. This subtopic addresses the potential for deriving power from waste rocket engine heat, warm soil, liquids (water, oils, hydraulic fluids), kinetic motion, piezoelectric materials, or various naturally occurring energy sources, etc. Development of energy harvesting (both capture and conversion) technologies would also address the national need for novel new energy systems and alternatives to reduce energy consumption.

Areas of special focus for this subtopic include consideration of:

- Innovative technologies for the efficient capture and/or conversion of acoustic, kinetic, and thermal energy types.
- Technologies which can work either under typical ambient environments for the above energy types and/or under high intensity energy environments for the above energy types as might be found in propulsion testing and launch facilities.
- As above, energy capture and conversion technologies that can work in very harsh environments such as those which are very hot and/or ablative (e.g., in the proximity of rocket exhaust) and/or very cold (e.g., temperatures associated cryogenic propellants) may be of interest.
- Innovations in miniaturization and suitability for manufacturing of energy capture and conversion systems so as to be used towards eventual powering of assorted sensors and IT systems on vehicles and infrastructures.
- High efficiency and reliability for use in environments that may be remote and/or hazardous and having low maintenance requirements.
- Employ green technology considerations to minimize impact on the environment and other resource usage.

Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above because they offer a wide spectrum of energy types and energy intensities to capture and convert. Additional Federal mandates require the optimization of current energy use and development of alternative energy sources to conserve on energy and to enhance the sustainability of these and other facilities.

Specific emphasis is on technologies which can be demonstrated in a ground test environment and have the ability/intention to be extrapolated for in-space applications such as on space vehicles, platforms or habitats. Energy harvesting technologies to generate higher power output than what is presently on the market are a highly desired to an expected outcome from this subtopic.

Phase I will develop feasibility studies and demonstrate through proof-of-concept demonstrations. Phase II will develop prototypical hardware and demonstrate infusion readiness to be incorporated into other products.
Robotics, Tele-Robotics and Autonomous Systems Topic T4
The topic for Robotics, Tele-Robotics and Autonomous Systems, consists of seven technology subareas: Sensing and Perception; Mobility; Manipulation; Human-Systems Integration; Autonomy; Autonomous Rendezvous and Docking (AR&D); and Robotics, Tele-Robotics and Autonomous Systems Engineering. Robotics, Tele-Robotics and Autonomous Systems supports NASA space missions with the development of new capabilities, and can extend the reach of human and robotic exploration through a combination of dexterous robotics, better human/robotic interfaces, improved mobility systems, and greater sensing and perception. The Robotics, Tele-Robotics and Autonomous Systems topics focuses on several key issues for the future of robotics and autonomy: enhancing or exceeding human performance in sensing, piloting, driving, manipulating, and rendezvous and docking; development of cooperative and safe human interfaces to form human-robot teams; and improvements in autonomy to make human crews independent from Earth and make robotic missions more capable.

Sub Topics:

T4.01 Dynamic Servoelastic (DSE) Network Control, Modeling and Optimization

Lead Center: AFRC
Participating Center(s): ARC, JPL, LaRC

This subtopic addresses advanced control-oriented techniques for dynamic servoelastic (DSE) terrestrial, planetary, and space environment flight systems using distributed network sensor and control systems. Methods include modeling, simulation, optimization and stabilization of DSE systems to actively and/or adaptively control structural dynamic geometry/topology, vibration, atmospheric and intraspace disturbances, static/dynamic loads, and other structural dynamic objectives for enhanced dynamic servoelastic performance and stability characteristics.

- DSE control for performance enhancements while minimizing dynamic interaction.
- Flexible aircraft and spacecraft stabilization and performance optimization.
- Modeling and system identification of distributed DSE dynamics.
- Sensor/actuator developments and modeling for distributed DSE control.
- Uncertainty modeling of complex DSE system behavior and interactions.
- Distributed networked sensing and control for vehicle shape, vibration, and load control.

This subtopic also addresses capabilities enabling design solutions for performance and environmental challenges of future air and space vehicles. Research in revolutionary aerospace configurations include lighter and more flexible materials, improved propulsion systems, and advanced concepts for high lift/performance and drag/energy reduction. This subtopic targets efficiency and environmental compatibilities requiring performance challenges and novel control-oriented techniques for aero-servoelastic considerations which are gaining prevalence in advanced aerospace flight vehicles, atmospheric and extra-terrestrial.

Technical elements for the Phase I proposals may also include:

- Mission/maneuver adaptivity with dissipative optimal energy-force distribution.
- Data-driven multi-objective DSE control with physics-based sensing.
- Robust sensing-control-communication networks for sensor-based distributed control.
- Compressive information-based sensing and information structures.
- Evolving systems as applied to self-assembling and robotic maneuvering.
- Scalable and evolvable information networks with layering architectures.
- Modular architectures for distributed autonomous aerospace systems.
- Multi-objective, multi-level control and estimation architectures.
- Distributed multi-vehicle dynamics analysis and visualization with complex simulations.
- Reduced order modeling capable of substructure coupling of nonlinear materials.

Development of distributed sensory-driven control-oriented DSE systems is solicited to enable future flight vehicle concepts and designs that manage structural dynamic uncertainty on a vehicle's overall performance. Proposals should assist in revolutionizing improvements in performance to empower a new generation of air and space vehicles to meet the challenges of terrestrial and commercial space concerns with novel concepts and technology.
developments in systems analysis, integration and evaluation. Higher performance measures include energy efficiency to reduce fuel burn and operability technologies that enable information network decompositions that have different characteristics in efficiency, robustness, and asymmetry of information and control with tradeoff between computation and communication.

Advanced mission applicability in Phase II should show the ability of aerospace GN&C systems to achieve mission objectives as a function of GN&C sensor performance, vehicle actuation/power/energy, and the ability to jointly design them as onboard-capable, real-time computing platforms with applicable environmental effects and robust guidance algorithms.

State of the Art

This subtopic will:

- Provide capabilities that would enable new projects and missions that are not currently feasible, using distributed sensing and controls for network processing.
- Impact multiple missions in NASA space operations and science, earth science, and aeronautics.
- Be influential across aerospace and non-aerospace disciplines with dynamic interactions.

Potential technical impacts are:

- Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
- Weight minimization through dynamic servoelastic control.
- Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

New technologies proposed should have the potential to impact the following NASA missions:

- Data availability for science missions.
- Mission planning.
- Autonomous rendezvous/docking technology.
- Environmental monitoring for human habitation.

Apart from NASA missions, the aeronautics technology could be adapted for development and use in autonomous operation of wind/ocean energy and smart space power grid systems in dynamic environments. There are number of advantages to exploring this subtopic technology:

- Increase in autonomy and fuel efficiency of coordinated robotic vehicles and sub-components.
- Improved science, atmospheric, and reconnaissance data.
- Cost, risk and reliability of flight vehicles for a terrestrial, planetary, or space mission.
- Inter-networks with improved dynamic behavior.

Potential technical impacts are:

- Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
- Weight minimization through dynamic servoelastic control.
- Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

T4.02 Regolith Resource Robotic
Using resources in space is the first step towards human self-sufficiency while expanding its presence into the Solar System. The use of robotics for In-Situ Resource Utilization (ISRU) in outer space on various planetary bodies is essential since ISRU requires large quantities of local regolith that must be acquired and processed by capable machines. In some cases, this will happen prior to crew arrival on site, or it will take place at a remote destination where the crew cannot spend much time due to radiation exposure limits or other constraints. In addition, communications latencies at remote locations such as Asteroids mandate autonomous robotics applications.

The first step towards using resources derived from small bodies in space, Mars, Mars Moons and Earth’s Moon, such as water, volatiles, metals and organic compounds, is to visit a target body, prospect it with sample acquisition devices and subsequently do characterization of these samples. This data will feed into eventual missions and methods for using resources in outer space by mining the ore on these target bodies and then transforming it into useful products via In-Situ Resource Utilization (ISRU) and advanced manufacturing techniques such as Additive Manufacturing and Construction. For these reasons, resource prospecting, identification and sampling regolith for characterization are priorities in this sub-topic.

Proposals are sought for innovative resource prospecting mission concepts, technology development, and demonstrations.

Technologies include sample acquisition methods and devices, regolith anchoring methods, autonomous conops, sub-surface access, excavation, specialized sensors, dust lofting mitigation, perception in dusty environments, mobility methods, surveying, remote sample characterization, geodetic mapping, replenishing and transferring robotic commodities such as propellants, electric power, data transfer, pneumatics and robust interfaces for commodity transfer.

Future prospecting missions include:

- Water/Ice on Mars, Mars moons or Earth’s Moon.
- Micro-gravity Near Earth Object (NEO) operations to prospect/sample surface resources.
- Lava tubes/shadowed crater cold traps on planetary surfaces to characterize volatiles accumulation.

Communication and Navigation Topic T5
Communications and Navigation Systems, consists of six technology subareas: optical communication and navigation; radio frequency communication; internetworking; position, navigation and timing; integrated technologies; and revolutionary concepts. Communication links are the lifelines to spacecraft, providing commanding, telemetry, and science data transfers as well as navigation support. Therefore, the Communications and Navigation Systems Technology Area supports all NASA space missions. Advancement in communication and navigation technology will allow future missions to implement new and more capable science instruments, greatly enhance human missions beyond Earth orbit, and enable entirely new mission concepts.

Sub Topics:

**T5.01 Autonomous Communications Systems**

*Lead Center: GRC*

*Participating Center(s): GSFC*

Future missions require networked comms systems that can support greater levels of autonomy and possess cognizance of the local environmental conditions and awareness of the state of other assets in the comms network for enhanced reach back and data delivery. ACS offer potential to improve overall system performance through automated sensing of local and system level conditions, rapid analysis and responsive configuration control.

Innovations are sought to enable an ACS to:

- Learn through experience to enhance adaptability to nominal and anomalous operations.
- Establish self-configurable network connections.
- Exchange information autonomously.
- Sense local conditions and dynamically maximize performance.
- Mitigate system-level effect of outages, delays, disruptions and interference.
- Leverage capabilities of flexible receivers, software-defined radios (SDRs), cognitive radios, network routers and storage, and ground assets to increase system-level autonomy, capacity and efficiency.

Potential deliverables may include a demo of ACS concept(s), enhanced comms component(s) through a clever innovation, or prototype of an element that enables a higher level of automation, performance, or efficiency at the system level.

State of the Art

Current spaceflight transceivers perform comms and some navigation functions. SDRs are reconfigurable. Use of GPS for location determination is becoming common. However, most transceivers, SDRs and ground assets operate independently under closely coordinated control. They are not yet cognitive of their local environmental conditions or the overall comms network capabilities and status, and unable to learn and improve.

Compelling need for this Subtopic

NASA SMD and HEOMD conduct robotic and human missions from low Earth orbit to deep space, in spacecraft as varied as constellations of CubeSats to human-rated orbiters and landers. The Space Communications and Navigation (SCaN) Program provides infrastructure, technologies and standards enable these missions. ACS offers the potential to sense and exploit knowledge of local and system-wide capabilities and conditions for efficient use of available comms network assets and maximum performance.

STMD/NASA/NARP/National Goals

SCaN Goals include: To implement a networked communication and navigation infrastructure across space; and to evolve its infrastructure to provide the highest data rates feasible for both robotic and human exploration missions.

Human Health, Life Support and Habitation Systems Topic T6

Human Health, Life Support and Habitation Systems, includes technologies necessary for supporting human health and survival during space exploration missions and consists of five technology subareas:

- Environmental control and life support systems and habitation systems.
- Extravehicular activity systems.
- Human health and performance.
- Environmental monitoring, safety, and emergency response.
- Radiation.

These missions can be short suborbital missions, extended microgravity missions, or missions to various destinations, and they experience what can generally be referred to as “extreme environments” including reduced gravity, high radiation and UV exposure, reduced pressures, and micrometeoroids and/or orbital debris.

Sub Topics:

T6.01 Gas Sensing Technology Advancements for Spacesuits

Lead Center: JSC

Space suit life support systems are critically necessary for the successful support of the International Space Station (ISS) and future human space exploration missions for in-space micro-gravity EVA and planetary surface operations. NASA has experienced a history of failures with the existing carbon dioxide (CO\textsubscript{2}) gas sensor for the current Extravehicular Mobility Unit (EMU) due to excess moisture in the suit. In addition, NASA is presently developing an Advanced EMU (AEMU) for exploration missions. These missions will require a robust, lightweight, and maintainable Portable Life Support System (PLSS). The PLSS attaches to the space suit pressure garment and provides approximately an 8 hour supply of oxygen for breathing, suit pressurization, ventilation; humidity, trace- contaminant, carbon dioxide (CO\textsubscript{2}) removal; and a thermal control system for crew member metabolic heat.
rejection. Innovative technologies and technology advancements are needed for the partial pressure gas sensors in the PLSS. Therefore, based on current and future EVA applications, advanced CO\textsubscript{2} gas sensing methods are needed that can tolerate ~100\% oxygen, direct water contact (Relative Humidity 0-100\%), 3-23.5 psia operating pressures, and CO\textsubscript{2} ranges of 0-30 mmHg. Additional attributes needed include low mass and volume, low maintenance, and radiation hardened or radiation tolerant. Integration of other sensing capabilities such as ammonia (NH\textsubscript{3} 0-50 ppm) and oxygen (0-100\%) is desirable.

**T6.02 Space Weather**

*Lead Center: GSFC*

*Participating Center(s): JSC*

Radiation hazards constitute one of the most serious risks to future human and robotic missions beyond Low-Earth Orbit, and particularly to long-duration, long-distance space missions. The main contributors to space radiation are Galactic Cosmic Rays (GCRs) and Solar Particle Events (SPEs). The latter is the more unpredictable of the two and is associated with most energetic solar eruptions: flares and coronal mass ejections; at the same time, SPEs are capable of inducing acute and profound effects on humans and on spacecraft components. Penetrating particle radiation from SPEs adversely affect aircraft avionics, communication and navigation, and potentially the health of airline crews and passengers on polar flights. SPEs also constitute major hazards for astronauts performing EVAs (Extra-Vehicular Activities) on board the International Space Station (ISS). Characterizing and predicting the dynamic variation of the radiation environment is a crucial capability, enabling personnel to take preventive measures to mitigate the potential risks, and facilitating adoption of the proper mitigation strategy. Many questions regarding space radiation have yet to be answered, and numerous challenges remain, such as improving the forecasting capability of the dynamic radiation environment (particularly SPEs), coupling the radiation environment models with engineering models of radiation effects on specific instruments or spacecraft hardware, and achieving a quantitative measure of human or space assets' response to radiation storms. The goal of the current opportunity is to help address the challenges by focusing on investigations that can potentially lead to longer-range (2-3 days) forecasting of SPEs (or at least an improved all-clear SPE forecasting capability), as well as those which couple radiation environment models with engineering models of radiation effects so that single-event effects on specific hardware and instruments can be predicted. Investigations that take an integrated approach, combining observation, theory and modeling, will be preferred. Those submitting proposals are urged to take advantage of relevant available observations (such as those from SDO, STEREOs, ACE, MAVEN, MSL/RAD, LRO, etc). The potential outcome will benefit all NASA missions, both robotic and manned, current and future. The goal is in line with NASA’s Living with a Star Program ([http://lws.gsfc.nasa.gov](http://lws.gsfc.nasa.gov)) and Human Research Roadmap ([http://humanresearchroadmap.nasa.gov](http://humanresearchroadmap.nasa.gov)).

**Human Exploration Destination Systems Topic T7**

Reserved for future Solicitations

**Sub Topics:**

- Science Instruments, Observatories and Sensor Systems Topic T7

Science Instruments, Observatories, and Sensor Systems addresses technologies that are primarily of interest for missions sponsored by NASA’s Science Mission Directorate and are primarily relevant to space research in Earth science, heliophysics, planetary science, and astrophysics. This topic consists of three Level 2 technology subareas:

  - Remote sensing instruments/sensors.
  - Observatories.
  - In situ instruments/sensors.

**T8.01 Technologies for Planetary Compositional Analysis and Mapping**

*Lead Center: JPL*

*Participating Center(s): GSFC, LaRC*

This subtopic is focused on developing and demonstrating technologies for both orbital and in situ compositional...
analysis and mapping that can be proposed to future planetary missions. Technologies that can increase instrument resolution, precision and sensitivity or achieve new and innovative scientific measurements are solicited. For example missions, see [http://science.hq.nasa.gov/missions](http://science.hq.nasa.gov/missions). For details of the specific requirements see the National Research Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 [http://solarsystem.nasa.gov/2013decadal](http://solarsystem.nasa.gov/2013decadal).

Possible areas of interest include:

- Improved sources such as lasers, LEDs, X-ray tubes, etc. for imaging and spectroscopy instruments (including Laser Induced Breakdown Spectroscopy, Raman Spectroscopy, Deep UV Raman and Fluorescence spectroscopy, Hyperspectral Imaging Spectroscopy, and X-ray Fluorescence Spectroscopy).
- Improved detectors for imaging and spectroscopy instruments (e.g., flight-compatible iCCDS and other time-gated detectors that provide gain, robot arm compatible PMT arrays and other detectors requiring high voltage operation, detectors with improved UV and near-to-mid IR performance, near-to-mid IR detectors with reduced cooling requirements). Technologies for 1-D and 2-D raster scanning from a robot arm. Novel approaches that could help enable in situ organic compound analysis from a robot arm. Novel approaches that could help evaluate real-time on a planetary surface to guide rover targeting, sample selection (for missions involving sample return), and science optimization of data returned to earth. Other technologies and approaches (e.g., improved cooling methods) that could lead to lower mass, lower power, and/or improved science return from instruments used to study the elemental, chemical, and mineralogical composition of planetary materials. Improved technologies for the handling and fine manipulation of solid or powdered surface samples that could be coupled to robotic arm- or body-mounted analytical instruments.

Projects selected under this subtopic should address at least one of the above areas of interest. Multiple-area proposals are encouraged. Proposers should specifically address:

- The suitability of the technology for flight applications, e.g., mass, power, compatibility with expected shock and vibration loads, radiation environment, interplanetary vacuum, etc. Advantages of the proposed technology compared to the competition. Relevance of the technology to NASA's planetary exploration science goals.

Phase I contracts will be expected to demonstrate feasibility, and Phase II contracts will be expected to fabricate and complete laboratory testing on an actual instrument/test article.

**T8.02 Visible to Far-Infrared Absolute Radiance Developments**

**Lead Center:** LaRC

**Participating Center(s):** GSFC

This solicitation seeks to advance the state of the art in absolute radiance measurements in the visible through the far-infrared (0.3 - 50 µm wavelength). Technologies to increase accuracy, precision, and sensitivity of absolute radiance measurements are desired. These wavelengths are of specific interest to remote sensing applications for both Earth science and planetary exploration missions.

Areas of interest include:

- Develop detector technologies to improve absolute radiance measurements in the infrared (1 - 50 µm wavelength) by increasing sensitivity, decreasing noise levels, and reducing or removing cooling requirements.
- Study and thoroughly characterize the non-linearities present in infrared detectors, specifically pyroelectric and mercury cadmium telluride (MCT), in the 5 - 50 µm wavelength region.
- Develop detector technologies to improve absolute radiance measurements in the visible to near infrared (0.3 - 8 µm wavelength).
• Develop novel compact lightweight high performance blackbody calibration source that may be enabled by recent developments in high emissivity surface treatments.
• Develop revolutionary compact, lightweight, and high performing infrared spectrometer (5 - 50 µm wavelength).

Proposals should specifically address one or more of the previously listed areas and include:

• Advantages and improvements of the proposed technology relative to current standards.
• Relevance of the technology to NASA’s science goals.

Phase I deliverables - Feasibility study and documentation of clear path to working prototype in Phase II for hardware topics or complete report characterizing infrared detector non-linearities.

Phase II deliverables - Working prototype hardware with thorough documentation of development and complete testing and characterization results.

Entry, Descent and Landing Systems Topic T9
Entry, Descent, and Landing, consists of four sub-technology areas:

• Aeroassist and entry.
• Descent.
• Landing.
• Vehicle systems technology.

Entry, Descent and Landing (EDL) is a critical technology that enables many of NASA’s landmark missions, including Earth reentry, Moon landings, and robotic landings on Mars. The EDL topic defines entry as the phase from arrival through hypersonic flight, with descent being defined as hypersonic flight to the terminal phase of landing, and landing being from terminal descent to the final touchdown. EDL technologies can involve all three of these mission phases, or just one or two of them.

Sub Topics:

**T9.01 Navigation and Hazard Avoidance Sensor Technologies**

Lead Center: LaRC

Participating Center(s): JSC

Missions to solar systems bodies must meet increasingly ambitious objectives requiring highly reliable “soft landing”, “precision landing”, and “hazard avoidance” capabilities. Robotic missions to the Moon and Mars demand landing at pre-designated sites of high scientific value near hazardous terrain features, such as escarpments, craters, slopes, and rocks. Missions aimed at paving the path for colonization of the Moon and human landing on Mars need to execute onboard hazard detection and precision maneuvering to ensure safe landing near previously deployed assets. Asteroid missions require precision rendezvous, identification of the landing or sampling site location, and navigation to the highly dynamic object that may be tumbling at a fast rate. NASA seeks sensor technologies enabling these missions to solar system bodies. The same sensor or sensor component technologies can also benefit space operations such as satellite servicing and optical communication.

Sensor and sensor component technologies are sought for providing measurement of vehicle relative proximity and velocity, bearings, and high resolution 3-dimensional images during the approach to the targeted body. Also of interest are sensors capable of measuring atmospheric winds and density for aiding navigation and guidance of landing vehicles in general and large hypersonic decelerators in particular. The proposals should target advanced sensor technologies for eventual space utilization. Phase I research should demonstrate the technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from an aircraft platform or rocket-power terrestrial test vehicles. The component and sensor system technologies being sought include but limited to the following list:

• Highly sensitive Flash lidar camera including 2-D detector array, associated readout integrated circuit
(ROIC), and drive/control electronics. Operational wavelength range 1.06-1.54 micron, the camera shall be capable of providing image frames greater than 60k pixels at 20 Hz with better than 5 cm range precision.

- Very compact and rugged laser transmitter operating in the 1.0 µm – 1.6 µm wavelength range with an output pulse energy of 30 mJ to 60 mJ, pulse width of about 6 nsec, and repetition rate of 20 Hz to 50 Hz suitable for flash lidars. The proposed laser must show path in maturing for operation in space environment.
- Ultra compact or micro-chip lasers generating 0.2 mJ - 2 mJ in 1.0 µm – 1.6 µm wavelength range. Laser pulse width must be less than 5 nsec and its beam quality better than 2.0 M². The laser must operate at greater than 20 Hz, preferably adjustable to over 50 Hz.
- Compact and rugged single-frequency CW laser systems operating at 1.55 micron wavelength region. Proposed lasers must be able to generate at least 5 W of power with less than 5 KHz linewidth over a tunable range of about 50 nm. Systems must be highly wavelength stable and come with full supporting electronic systems for thermal and power control. The lasers must be developed with space environment considerations and demonstrate a clear path to space.
- Non-mechanical laser beam steering devices capable of 2-axis pointing laser beams over +/- 25 degrees angle.

Nanotechnology Topic T10
Reserved for future Solicitations
Sub Topics:

Modeling, Simulation, Information Technology and Processing Topic T11
Modeling, Simulation, Information Technology and Processing consists of four technology subareas, including computing, modeling, simulation, and information processing. NASA’s ability to make engineering breakthroughs and scientific discoveries is limited not only by human, robotic, and remotely sensed observation, but also by the ability to transport data and transform the data into scientific and engineering knowledge through sophisticated needs. With data volumes exponentially increasing into the petabyte and exabyte ranges, modeling, simulation, and information technology and processing requirements demand advanced supercomputing capabilities.

Sub Topics:

T11.01 Information Technologies for Intelligent and Adaptive Space Robotics
Lead Center: ARC
Participating Center(s): JPL, JSC

The objective of this subtopic is to develop information technologies that enable robots to better support space exploration. Improving robot information technology (algorithms and software) is critical to improving the capability, flexibility, and performance of future missions. In particular, the NASA "Robotics, Tele-Robotics, and Autonomous Systems" roadmap (TA04) indicates that extensive and pervasive use of robots can significantly enhance exploration missions that are progressively longer, complex, and operate with fewer ground control resources.

The performance of intelligent robots is directly linked to the quality and capability of the information technologies used to build and operate them. Thus, proposals are sought that address the following technology needs:

- Advanced robot user interfaces that facilitate distributed collaboration, geospatial data visualization, summarization and notification, performance monitoring, and physics-based simulation. This does NOT include user interfaces for direct teloperation / purely manual control, telepresence, or virtual reality. The primary objective is to enable more effective and efficient interaction with robots remotely operated with discrete commands or supervisory control.
- Mobile robot navigation for operations in man-made (inside the International Space-Station) and unstructured environments (asteroids, Moon, Mars). Emphasis on multi-sensor data fusion, obstacle detection, and proximity ops. The primary objective is to radically and significantly increase the performance of mobile robot navigation through advanced on-board sensors, perception algorithms and software.
- Robot software architecture that supports adjustable autonomy, on-board health management and prognostics, automated data triage, data management, and data distribution (middleware). The primary objective is to facilitate the creation, extensibility and maintenance of complex robot systems.

Deliverables to NASA:
• Identify scenarios and use cases.
• Define specifications based on design trades.
• Develop concepts to address use cases.
• Build and test prototype systems.
• Perform technology demonstrations.

T11.02 Computational Simulation and Engineering

Lead Center: JPL

Computational Optimization

Proposals are solicited for developing numerical methods and tools that enable robust continuous and discrete optimization as well as uncertainty quantification for physics based computational models. There are many different optimization methods and implementations of some of these methods are available in commercial and open-source form. These methods typically use a "function call" to evaluate a performance model to be optimized. We seek proposals to develop new methods and tools for developing an integrated performance model that represents the behavior of a system (or component) by integrating multi-disciplinary performances. We are not interested in discipline-specific performance models (e.g., a FEA model of a solar panel dynamics). We are interested in model representations that capture different physical phenomena in a system (e.g., structural, dynamic, thermal, geometry, etc.). Our objective is to enable automated and/or human-in-the-loop optimization of complex, multi-disciplinary system models. We are also interested in uncertainty quantification of these models. Methods or tools that leverage discipline-specific, commercial packages that are commonly used in engineering design at NASA and other relevant fields (e.g., DoD, automotive, aerospace, etc.) are of high interest.

The integrated performance model should clearly demonstrate how it may be used to first evaluate performance against different requirements and then improved (automated or human-guided) to give an optimal performance (in a weighted sum manner) against the different requirements. Intrinsic in this is the parameterization of the discipline-specific aspects of the performance model and exposing the parameters for optimization. In Phase I, it is expected that the proposer will demonstrate integration of at least two different disciplines. One of these disciplines should be geometry via Computer Aided Design software. If successful, Phase II will mature the work-flow and develop integration with a number of different discipline specific tools. Given the maturity of discipline specific tools, we expect the TRL level at the end of Phase II to be 4-6.

Virtual Worlds

Proposals are solicited for development of computational tools that enable rapid demonstration of mission concepts. The intent of such a tool is to enable non-experts in animation to rapidly build mission scenarios and visually express their concepts in a virtual world. These tools should enable full 3-D visualization by importing of CAD parts of electromechanical systems (e.g., rovers, landers, orbiters), environment models (height field maps with textures for terrain, star maps and planetary bodies), animation functionality to show temporal progression and movement of appropriate objects in the scene. The tool should support animation of flexible bodies (e.g., solar panel vibrations) along with articulation of components. The tool should feature a ray-tracing engine for good quality visualization with shadowing, ambient lighting, etc. The tool should also be able to demonstrate terrain artifacts such as rocks, dust and ejecta as both static and dynamic objects. An example of a static artifact may be a rock pile that does not move during the animation while a dynamic artifact may be dust rising from a lander thruster interaction with terrain. Note that the emphasis is on visualization and not necessarily on the physics of the problem. However, the tool should have API for integration with physics engines (e.g., ODE, Bullet, Proprietary Code) so that physics simulations can be used to control temporal progression of a scene. There should also be a functionality to write simple scripts for animating the virtual entities. There should be an avenue for developing a library of animation objects (e.g., rovers, terrains and locations) for re-use in later concept developments. The tools should be cross platform and enable development of animations or movies. The tool should take advantage of graphics processors or enable use of cluster computers for fast rendering of complex scenes. Alternately, the tool could feature a server-based functionality where the front-end user-interactions are through a webpage (using Java, HTML or other alternatives) and the computations are remotely conducted. Support for multiple concurrent users for content creating is desired. Ease of user interaction is key to the success of the tools. It is expected that at the end of Phase I, the performer will deliver an architecture document that captures the full intent of the tool. Similarly, performer will deliver software prototype of the implementation of the tool. It is expected that the software
at the end of Phase I will be a prototype and may not have all features implemented or debugged. Performer will identify options for desired licensing options for the software to be developed for Phase II. At the end of Phase II, the performer will deliver all source code associated with the tool and verification test cases demonstrating all the proposed features within the software. The performer will also deliver a document summarizing the installation and usage of the tool and appropriate licensing options. In case of use of any third party software (e.g., open-source code) in this effort, the performer will deliver an acknowledgement that they have complied with appropriate licensing agreements. The anticipated TRL level at the end of Phase II is 5-6.

Materials, Structures, Mechanical Systems and Manufacturing Topic T12
Materials, Structures, Mechanical Systems, and Manufacturing
This topic is extremely broad, covering five technology areas: materials, structures, mechanical systems, manufacturing, and cross-cutting technologies. The topic consists of enabling core disciplines and encompasses fundamental new capabilities that directly impact the increasingly stringent demands of NASA science and exploration missions.

Sub Topics:

T12.01 Advanced Structural Health Monitoring

Lead Center: LaRC
Participating Center(s): JSC

This subtopic seeks new and innovative technologies in structural health monitoring (SHM), integrated vehicle health management (IVHM) systems, their corresponding analysis tools, and smart materials. Advanced structural composites and sensors with the potential to enable or enhance distributed damage detection for aerospace vehicles and spacecraft are sought. Example systems should allow for detection of damage states including corrosion, electrostatic discharge, delamination, cracking, microcracking, porosity, fiber breakage, impact damage, micrometeoroid orbital debris impacts on orbit, and general material property degradation due to aging. The innovative introduction of smart aspects to composite structures, for example, autonomous healing, shape memory, or piezoelectricity, is of interest. Such structures could allow for the realization of the mass reduction that composite materials have promised for spacecraft through enhanced damage tolerance. The addition of multi-functionality would be an asset towards improving overall system efficiency.

NASA is evaluating advanced composite structures due to their relatively high strength, light weight, and potential low production cost. Currently, damage tolerance concerns require that much thicker and heavier composite structures be manufactured to compensate for potential damage, and therefore the weight savings that composites promise has not yet been achieved. Smart sensor systems and smart structural composites could address this issue of damage tolerance, thereby allowing composites to be far lighter. Development of advanced technologies is required to improve the capability to better detect damage during manufacture and lifetime. Determining the extent of damage and/or autonomous healing of damage will also reduce the complexity of composite maintenance and increase performance lifetime and reliability.

This STTR seeks to enable the creation of smart composite systems and smart sensor systems for extended structural life monitoring and/or self-repair. Primary material systems for this STTR can include metals, but it is highly desirable to target carbon composite structures. Inclusion of smart or enhanced materials such as piezoelectric, shape memory, and self-healing will be highly advantageous. Other potential sensors are: Surface Acoustic Wave (SAW)-based sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces direct-write film sensors, and others. Sensor systems can include sensors that can be applied post-manufacture of the structure. All systems will provide information about location and extent of the structural deficiency. It is not required but considered highly advantageous to directly relate to a measurable material property such as remaining material strength, density, etc.

Suitable target structures include but are not limited to primary and secondary structures, including vehicle, habitat module, and pressure vessel structures. Target structures may be relevant to either existing or future aerospace vehicles and spacecraft. SHM and IVHM systems applicable to the International Space Station are especially of interest, though the scope of the solicitation is not limited to this application. This subtopic is not intended for materials coupon-level work only; proposed systems should have a targeted demonstrator structure identified as a deliverable.

In Phase I, composite samples or prototype sensor systems will be fabricated and tested to demonstrate basic functionality of the material or sensor system. The targeted demonstrator structure will be identified, and critical test
environments and associated performance predictions will be defined relative to the final operating environment. Deliverables include composite samples, sensors, associated test data, predictions, and lessons learned.

In Phase II, while full-scale demonstrators are not required, scaled-up systems will be built in application-appropriate geometries. Demonstrators will be tested in a simulated operational environment for demonstrate of performance in critical areas. Further scale-up requirements will be defined, and performance predictions will made for subsequent development phases. Deliverables will include samples and the associated test data, sensor hardware and predictions.

T12.02 High Temperature Materials and Sensors for Propulsion Systems
Lead Center: GRC

Advanced materials, structures and sensors are crosscutting technologies which are essential in the design, development and health maintenance/detection needs of components and subsystems that will be needed in future generations of aeronautics and space propulsion and power systems. Materials will require multiple or tailored functions that are designed to meet specific mission needs. Lightweight, high temperature, environmentally stable and multifunctional materials and reliable structures will be needed to meet the challenges of future aerospace systems. Improved temperature capability enables increased thermodynamic efficiency and improved performance.

- Develop innovative approaches to enhance the durability, processability, performance and reliability of advanced high temperature materials (metals, ceramics, polymers, high-strength fibers, composites, nanostructured materials and coatings to improve environmental durability.
- Develop and demonstrate hierarchical assembly of nano and microstructures to give ultra-lightweight materials with unique thermal, electrical, and/or mechanical properties.
- Multifunctional materials and structures as a means to reduce component weight.
- Physics based modeling tools that capture the modes of materials degradation in the extreme environments found in propulsion systems.

Innovative smart sensing methods and measurement techniques that can reliably assess component health in the harsh environments experienced in aerospace engines and vehicles that go beyond the limits of current sensing technology. Interest is in:

- Sensors and systems with a fast response, able to be used at high temperatures, low volume and weight, be minimally intrusive and possess high accuracy and reliability.
- Development of nano-sensor technology allowing sensors that are smaller, more energy efficient and the ability to provide more sensitive health assessments.
- Approaches to measure strain, temperature, heat flux, deflection, acoustics and/or acceleration of structural components.
- Integration of sensors into systems (wireless, wired or fiber optic).

T12.03 Advanced Bladder Materials for Inflatable Habitats
Lead Center: JSC

This subtopic solicits advanced bladder materials for use in inflatable structures. Inflatable structures are a solution for increasing the volume and decreasing the weight and launch package for habitats, airlocks, and potentially other crewed vessels. Ideal bladder materials are low permeability gas barriers, durable over time, and do not degrade due to effects such as cold flow. Low permeability bladder materials that can withstand extreme cold temperatures (-90 °F), recover, and then deploy at low temperatures (-30 °F and -50 °F) while still maintaining low permeability rates (goal of 1.5 cc/100in²/day/atm), are of particular interest. Multi-functional materials (self-healing, flame resistant, puncture resistant...) are also of interest, however, cold flexure is of prime concern. The bladder materials should also be low mass (goal of <6 oz./yd²) and be able to be manufactured into complex shapes (such as dual curvature). Developments can include material development and testing, and/or demonstration of manufacturing techniques.
Phase I and/or Phase II deliverables should include material identification and/or development, and bladder materials flexure tested at various temperatures (such as room temperature, -30 °F, and -50 °F) and then permeability tested at room temperature. In addition, bladder materials can be lightly packed and folded and then taken to even colder temperatures (for example; -90 °F, -75 °F, and/or -60 °F) for an extended period of time (24 hours to a few months), allowed to recover, unfolded at cold temperatures (-30 °F and -50 °F) and then permeability tested at room temperature. Bladder materials should demonstrate the ability to be manufactured into complex shapes. The colder temperature the bladder materials can withstand (cold storage and deployment) and still meet the permeability goal, after recovery, the better the results.

T12.04 Experimental and Analytical Technologies for Additive Manufacturing

Lead Center: MSFC
Participating Center(s): ARC, GRC, JSC, LaRC

Additive manufacturing is becoming a leading method for reducing costs, increasing quality, and shortening schedules for production of innovative parts and component that were previously not possible using more traditional methods of manufacturing. In the past decade, methods such as selective laser melting (SLM) have emerged as the leading paradigm for additive manufacturing (AM) of metallic components, promising very rapid, cost-effective, and on-demand production of monolithic, lightweight, and arbitrarily intricate parts directly from a CAD file. In the push to commercialize the SLM technology, however, the modeling of the AM process and physical properties of the resulting artifact were paid little attention. As a result, commercially available systems are based largely on hand-tuned parameters determined by trial and error for a limited set of metal powders. The system operation is far from optimal or efficient, and the uncertainty in the performance of the produced component is too large. This, in turn, necessitates a long and costly certification process, especially in a highly risk-aware community such as aerospace.

State of the Art

This topic seeks technologies that close critical gaps between SOA and needed technology in both experimental and analytical areas in materials design, process modeling and material behavior prediction to reduce time and cost for materials development and process qualification for SLM.

What is the compelling need for this Subtopic?

Additive manufacturing is largely an emerging technology that shows great promise for the defense, energy, aerospace, medical and commercial sectors. Technological advancements are needed in the areas of:

- Real-time additive manufacturing process monitoring for real-time material quality assurance prediction.
- Reduced-order physics models for individual phases of additive manufacturing technique.
- Analytical tools to understand effects of process variables on materials evolution.
- Digital models to standardize the use of structured light scanning or equivalent within manufacturing processes.
- Software for high-fidelity simulation of various SLM phases for guiding the development, and enabling the subsequent verification.

The technology enabling to further utilization and certification for aerospace components. Almost all NASA Centers have capability in additive manufacturing and will benefit from this technology. This technology will accelerate growth in commercial development.

STMD/NASA/NARP/National - The subtopic is highly consistent with the technology objectives within the Strategic Space Technology Investment Plan and the NASA’s technology roadmaps. The subtopic is also closely aligned with the National Manufacturing Initiative and the Materials Genome Initiative.

Ground and Launch Systems Processing Topic T13

The goal of this topic is to provide a flexible and sustainable US capability for ground processing as well as launch,
mission, and recovery operations to significantly increase safe access to space. The Ground and Launch Systems Processing topic consists of four technology subareas, including:

- Technologies to optimize the operational life-cycle.
- Environmental and green technologies.
- Technologies to increase reliability and mission availability.
- Technologies to improve mission safety/mission risk.

The primary benefit derived from advances in this technology area is reduced cost, freeing funds for other investments.

**Sub Topics:**

**T13.01 Advanced Propulsion System Ground Test and Launch Technology**

**Lead Center:** SSC  
**Participating Center(s):** KSC, MSFC

Rocket propulsion development is enabled by rigorous ground testing to mitigate the risk inherent in spaceflight. As next generation propulsion systems are developed matching/related advancements in test technologies to appropriately test the new propulsion systems as well as more overall advancements in test technologies are also required. This subtopic area seeks to develop advanced ground test component and systems technologies to reduce cost and schedule, to improve reliability and quality, and to increase safety in Rocket Propulsion Testing. Many of these types of technologies may also have benefit for launch operations. Specific technologies of interest:

- **Innovative Facility Components.** Efficient generation of high temperature (>2500°R), high flowrate (<60 lb/sec) hydrogen, devices for measurement of pressure, temperature, strain and radiation in a high temperature and/or radiation environment, Development of innovative rocket test facility components (e.g., valves, flowmeters, actuators, tanks, etc.) for ultra-high pressure (>8000 psi), high flow rate (>100 lbm/sec) and cryogenic environments. Robust and reliable component designs which are oxygen compatible and can operate efficiency in high vibro-acoustic, environments.

- **Advanced Test Facility Monitoring.** Embedded sensor systems to provide advanced diagnostics to monitor test facility parameters includes high-speed, simultaneous heat flux, temperature, pressure, strain and near-field acoustics. This includes remote monitoring of vacuum line, gas leaks and fire, where the use of wireless/self-powered sensors to eliminate power and data wires would be beneficial. The proposed innovative systems must lead to improved safety and reduced test costs by allowing real-time analysis of data, information, and knowledge through efficient interfaces to enable integrated awareness of the system condition by users.

- **Advanced Test Imaging & Analysis.** Advanced test imaging technologies providing ultra-high dynamic imaging ranges with frame rates suitable for high speed event reconstruction. The proposed innovative systems must be capable of imaging at better than 500 frames/sec, IRIG-B compatible, and with ultra-high contrast ratio. The image data must also be transferred and recorded in real time, remote from the camera optics. It must also be capable of recovering from saturated pixels from very bright objects. Ability to analyze object speed and trajectory through stereo imaging is highly desirable.

Phase I will develop feasibility studies, validate system concepts and possibly produce prototypes. Phase II will development prototype hardware and validate the technology readiness for meeting ground and launch propulsion test requirements.
Satellite missions. Currently these satellites can only be launched affordably as secondary payloads; but the number of these missions has outpaced available ride share opportunities. This limitation makes it difficult for small satellite missions to launch when needed and to attain the desired orbit with an acceptable risk.

A dedicated access to space also allows new and emerging technologies that increase capability and/or decrease costs to be demonstrated and qualified. Additive manufacturing is one example of such a technology. Technologies that are demonstrated and validated at the nano/micro scale can also be robustly infused into large launch vehicles where loads are not as severe.

Low cost, dedicated launch vehicles are required that will robustly meet the nano/micro satellite launch needs. This subtopic solicits technology proposals for propulsion stages of such a launcher. Specifically, the subtopic requests proposals for propulsion design tools and stages for application as booster stages, upper stages or orbit insertion stages. Stage concepts are sought that can be demonstrated within the schedule and budget of a Phase II STTR project with the following goals and constraints:

- Accepted proposals will be limited to stages that are applicable to existing or proposed architectures for orbital launch vehicles.
- A sub-orbital flight test is expected in Phase II. Additionally, the path from the sub-orbital flight test to orbital capability must be clearly defined.
- Demonstrations other than a sub-orbital flight test will be considered. However anything less than a sub-orbital flight test will require the documentation of the explicit path, including test plans and cost data, to an orbital-capable stage.
- Payload capabilities in the 5-50 kg range are targeted.
- Small launch vehicles are targeting total launch costs (fixed, reoccurring and range costs) in the $1-2 million range. Proposed stages should demonstrate costs that fit within this range.

Phase I activities should develop the data necessary to assert with confidence that the proposed technology solution has a clear path to meet the goal an affordable orbital launch vehicle. Phase II activities will include sub-orbital stage flight-testing for verification of functionality as well as substantiation of cost projections for the orbital stage.

Sub Topics:

Energy Harvesting Technology Development Topic T3.01
The NRC has identified a NASA Top Technical Challenge as the need to "Increase Available Power". Additionally, a NASA Grand Challenge is "Affordable and Abundant Power" for NASA mission activities. As such, novel energy harvesting technologies are critical toward supporting future power generation systems to begin to meet these challenges. This subtopic addresses the potential for deriving power from waste rocket engine heat, warm soil, liquids (water, oils, hydraulic fluids), kinetic motion, piezoelectric materials, or various naturally occurring energy sources, etc. Development of energy harvesting (both capture and conversion) technologies would also address the national need for novel new energy systems and alternatives to reduce energy consumption.

Areas of special focus for this subtopic include consideration of:

- Innovative technologies for the efficient capture and/or conversion of acoustic, kinetic, and thermal energy types.
- Technologies which can work either under typical ambient environments for the above energy types and/or under high intensity energy environments for the above energy types as might be found in propulsion testing and launch facilities.
- As above, energy capture and conversion technologies that can work in very harsh environments such as those which are very hot and/or ablative (e.g., in the proximity of rocket exhaust) and/or very cold (e.g., temperatures associated cryogenic propellants) may be of interest.
- Innovations in miniaturization and suitability for manufacturing of energy capture and conversion systems so as to be used towards eventual powering of assorted sensors and IT systems on vehicles and infrastructures.
- High efficiency and reliability for use in environments that may be remote and/or hazardous and having low maintenance requirements.
- Employ green technology considerations to minimize impact on the environment and other resource usage.
Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above because they offer a wide spectrum of energy types and energy intensities to capture and convert. Additional Federal mandates require the optimization of current energy use and development of alternative energy sources to conserve on energy and to enhance the sustainability of these and other facilities.

Specific emphasis is on technologies which can be demonstrated in a ground test environment and have the ability/intention to be extrapolated for in-space applications such as on space vehicles, platforms or habitats. Energy harvesting technologies to generate higher power output than what is presently on the market are a highly desired to an expected outcome from this subtopic.

Phase I will develop feasibility studies and demonstrate through proof-of-concept demonstrations. Phase II will develop prototypical hardware and demonstrate infusion readiness to be incorporated into other products.

**Sub Topics:**

- Dynamic Servoelastic (DSE) Network Control, Modeling and Optimization Topic T4.01
  This subtopic addresses advanced control-oriented techniques for dynamic servoelastic (DSE) terrestrial, planetary, and space environment flight systems using distributed network sensor and control systems. Methods include modeling, simulation, optimization and stabilization of DSE systems to actively and/or adaptively control structural dynamic geometry/topology, vibration, atmospheric and intraspace disturbances, static/dynamic loads, and other structural dynamic objectives for enhanced dynamic servoelastic performance and stability characteristics.
  - DSE control for performance enhancements while minimizing dynamic interaction.
  - Flexible aircraft and spacecraft stabilization and performance optimization.
  - Modeling and system identification of distributed DSE dynamics.
  - Sensor/actuator developments and modeling for distributed DSE control.
  - Uncertainty modeling of complex DSE system behavior and interactions.
  - Distributed networked sensing and control for vehicle shape, vibration, and load control.

This subtopic also addresses capabilities enabling design solutions for performance and environmental challenges of future air and space vehicles. Research in revolutionary aerospace configurations include lighter and more flexible materials, improved propulsion systems, and advanced concepts for high lift/performance and drag/energy reduction. This subtopic targets efficiency and environmental compatibilities requiring performance challenges and novel control-oriented techniques for aero-servoelastic considerations which are gaining prevalence in advanced aerospace flight vehicles, atmospheric and extra-terrestrial.

Technical elements for the Phase I proposals may also include:

- Mission/maneuver adaptivity with dissipative optimal energy-force distribution.
- Data-driven multi-objective DSE control with physics-based sensing.
- Robust sensing-control-communication networks for sensor-based distributed control.
- Compressive information-based sensing and information structures.
- Evolving systems as applied to self-assembling and robotic maneuvering.
- Scalable and evolvable information networks with layering architectures.
- Modular architectures for distributed autonomous aerospace systems.
- Multi-objective, multi-level control and estimation architectures.
- Distributed multi-vehicle dynamics analysis and visualization with complex simulations.
- Reduced order modeling capable of substructure coupling of nonlinear materials.

Development of distributed sensory-driven control-oriented DSE systems is solicited to enable future flight vehicle concepts and designs that manage structural dynamic uncertainty on a vehicle's overall performance. Proposals should assist in revolutionizing improvements in performance to empower a new generation of air and space vehicles to meet the challenges of terrestrial and commercial space concerns with novel concepts and technology developments in systems analysis, integration and evaluation. Higher performance measures include energy efficiency to reduce fuel burn and operability technologies that enable information network decompositions that have different characteristics in efficiency, robustness, and asymmetry of information and control with tradeoff between computation and communication.
Advanced mission applicability in Phase II should show the ability of aerospace GN&C systems to achieve mission objectives as a function of GN&C sensor performance, vehicle actuation/power/energy, and the ability to jointly design them as onboard-capable, real-time computing platforms with applicable environmental effects and robust guidance algorithms.

State of the Art

This subtopic will:

- Provide capabilities that would enable new projects and missions that are not currently feasible, using distributed sensing and controls for network processing.
- Impact multiple missions in NASA space operations and science, earth science, and aeronautics.
- Be influential across aerospace and non-aerospace disciplines with dynamic interactions.

Potential technical impacts are:

- Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
- Weight minimization through dynamic servoelastic control.
- Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

New technologies proposed should have the potential to impact the following NASA missions:

- Data availability for science missions.
- Mission planning.
- Autonomous rendezvous/docking technology.
- Environmental monitoring for human habitation.

Apart from NASA missions, the aeronautics technology could be adapted for development and use in autonomous operation of wind/ocean energy and smart space power grid systems in dynamic environments. There are number of advantages to exploring this subtopic technology:

- Increase in autonomy and fuel efficiency of coordinated robotic vehicles and sub-components.
- Improved science, atmospheric, and reconnaissance data.
- Cost, risk and reliability of flight vehicles for a terrestrial, planetary, or space mission.
- Inter-networks with improved dynamic behavior.

Potential technical impacts are:

- Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
- Weight minimization through dynamic servoelastic control.
- Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

Sub Topics:

Regolith Resource Robotic Topic T4.02

Using resources in space is the first step towards human self-sufficiency while expanding its presence into the Solar System. The use of robotics for In-Situ Resource Utilization (ISRU) in outer space on various planetary bodies is essential since ISRU requires large quantities of local regolith that must be acquired and processed by capable machines. In some cases this will happen prior to crew arrival on site, or it will take place at a remote destination where the crew cannot spend much time due to radiation exposure limits or other constraints. In addition, communications latencies at remote locations such as Asteroids mandate autonomous robotics.
The first step towards using resources derived from small bodies in space, Mars, Mars Moons and Earth’s Moon, such as water, volatiles, metals and organic compounds, is to visit a target body, prospect it with sample acquisition devices and subsequently do characterization of these samples. This data will feed into eventual missions and methods for using resources in outer space by mining the ore on these target bodies and then transforming it into useful products via In-Situ Resource Utilization (ISRU) and advanced manufacturing techniques such as Additive Manufacturing and Construction. For these reasons, resource prospecting, identification and sampling regolith for characterization are priorities in this sub-topic.

Proposals are sought for innovative resource prospecting mission concepts, technology development, and demonstrations.

Technologies include sample acquisition methods and devices, regolith anchoring methods, autonomous conops, sub-surface access, excavation, specialized sensors, dust lofting mitigation, perception in dusty environments, mobility methods, surveying, remote sample characterization, geodetic mapping, replenishing and transferring robotic commodities such as propellants, electric power, data transfer, pneumatics and robust interfaces for commodity transfer.

Future prospecting missions include:

- Water/Ice on Mars, Mars moons or Earth’s Moon.
- Micro-gravity Near Earth Object (NEO) operations to prospect/sample surface resources.
- Lava tubes/shadowed crater cold traps on planetary surfaces to characterize volatiles accumulation.

Sub Topics:

Autonomous Communications Systems Topic T5.01

Future missions require networked comms systems that can support greater levels of autonomy and possess cognizance of the local environmental conditions and awareness of the state of other assets in the comms network for enhanced reach back and data delivery. ACS offer potential to improve overall system performance through automated sensing of local and system level conditions, rapid analysis and responsive configuration control.

Innovations are sought to enable an ACS to:

- Learn through experience to enhance adaptability to nominal and anomalous operations.
- Establish self-configurable network connections.
- Exchange information autonomously.
- Sense local conditions and dynamically maximize performance.
- Mitigate system-level effect of outages, delays, disruptions and interference.
- Leverage capabilities of flexible receivers, software-defined radios (SDRs), cognitive radios, network routers and storage, and ground assets to increase system-level autonomy, capacity and efficiency.

Potential deliverables may include a demo of ACS concept(s), enhanced comms component(s) through a clever innovation, or prototype of an element that enables a higher level of automation, performance, or efficiency at the system level.

State of the Art

Current spaceflight transceivers perform comms and some navigation functions. SDRs are reconfigurable. Use of GPS for location determination is becoming common. However, most transceivers, SDRs and ground assets operate independently under closely coordinated control. They are not yet cognitive of their local environmental conditions or the overall comms network capabilities and status, and unable to learn and improve.

Compelling need for this Subtopic

NASA SMD and HEOMD conduct robotic and human missions from low Earth orbit to deep space, in spacecraft as varied as constellations of CubeSats to human-rated orbiters and landers. The Space Communications and
Navigation (SCaN) Program provides infrastructure, technologies and standards enable these missions. ACS offers the potential to sense and exploit knowledge of local and system-wide capabilities and conditions for efficient use of available comms network assets and maximum performance.

STMD/NASA/NARP/National Goals

SCaN Goals include: To implement a networked communication and navigation infrastructure across space; and to evolve its infrastructure to provide the highest data rates feasible for both robotic and human exploration missions.

Sub Topics:

Gas Sensing Technology Advancements for Spacesuits Topic T6.01
Space suit life support systems are critically necessary for the successful support of the International Space Station (ISS) and future human space exploration missions for in-space micro-gravity EVA and planetary surface operations. NASA has experienced a history of failures with the existing carbon dioxide (CO₂) gas sensor for the current Extravehicular Mobility Unit (EMU) due to excess moisture in the suit. In addition, NASA is presently developing an Advanced EMU (AEMU) for exploration missions. These missions will require a robust, lightweight, and maintainable Portable Life Support System (PLSS). The PLSS attaches to the space suit pressure garment and provides approximately an 8 hour supply of oxygen for breathing, suit pressurization, ventilation; humidity, trace- contaminant, carbon dioxide (CO₂) removal; and a thermal control system for crew member metabolic heat rejection. Innovative technologies and technology advancements are needed for the partial pressure gas sensors in the PLSS. Therefore, based on current and future EVA applications, advanced CO₂ gas sensing methods are needed that can tolerate ~100% oxygen, direct water contact (Relative Humidity 0-100%), 3-23.5 psia operating pressures, and CO₂ ranges of 0-30mmHg. Additional attributes needed include low mass and volume, low maintenance, and radiation hardened or radiation tolerant. Integration of other sensing capabilities such as ammonia (NH₃ 0-50 ppm) and oxygen (0-100%) is desirable.

Sub Topics:

Space Weather Topic T6.02
Radiation hazards constitute one of the most serious risks to future human and robotic missions beyond Low-Earth Orbit, and particularly to long-duration, long-distance space missions. The main contributors to space radiation are Galactic Cosmic Rays (GCRs) and Solar Particle Events (SPEs). The latter is the more unpredictable of the two and is associated with most energetic solar eruptions: flares and coronal mass ejections; at the same time, SPEs are capable of inducing acute and profound effects on humans and on spacecraft components. Penetrating particle radiation from SPEs adversely affect aircraft avionics, communication and navigation, and potentially the health of airline crews and passengers on polar flights. SPEs also constitute major hazards for astronauts performing EVAs (Extra-Vehicular Activities) on board the International Space Station (ISS). Characterizing and predicting the dynamic variation of the radiation environment is a crucial capability, enabling personnel to take preventive measures to mitigate the potential risks, and facilitating adoption of the proper mitigation strategy. Many questions regarding space radiation have yet to be answered, and numerous challenges remain, such as improving the forecasting capability of the dynamic radiation environment (particularly SPEs), coupling the radiation environment models with engineering models of radiation effects on specific instruments or spacecraft hardware, and achieving a quantitative measure of human or space assets' response to radiation storms. The goal of the current opportunity is to help address the challenges by focusing on investigations that can potentially lead to longer-range (2-3 days) forecasting of SPEs (or at least an improved all-clear SPE forecasting capability), as well as those which couple radiation environment models with engineering models of radiation effects so that single-event effects on specific hardware and instruments can be predicted. Investigations that take an integrated approach, combining observation, theory and modeling, will be preferred. Those submitting proposals are urged to take advantage of relevant available observations (such as those from SDO, STEREOs, ACE, MAVEN, MSL/RAD, LRO, etc). The potential outcome will benefit all NASA missions, both robotic and manned, current and future. The goal is in line with NASA's Living with a Star Program (http://lws.gsfc.nasa.gov [1]) and Human Research Roadmap (http://humanresearchroadmap.nasa.gov/ [2]).

Sub Topics:

Technologies for Planetary Compositional Analysis and Mapping Topic T8.01
This subtopic is focused on developing and demonstrating technologies for both orbital and in situ compositional analysis and mapping that can be proposed to future planetary missions. Technologies that can increase instrument resolution, precision and sensitivity or achieve new and innovative scientific measurements are solicited. For example missions, see (http://science.hq.nasa.gov/missions [3]). For details of the specific requirements see the National Research Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 (http://solarsystem.nasa.gov/2013decadal/ [4]).

Possible areas of interest include:
Improved sources such as lasers, LEDs, X-ray tubes, etc. for imaging and spectroscopy instruments (including Laser Induced Breakdown Spectroscopy, Raman Spectroscopy, Deep UV Raman and Fluorescence spectroscopy, Hyperspectral Imaging Spectroscopy, and X-ray Fluorescence Spectroscopy).

Improved detectors for imaging and spectroscopy instruments (e.g., flight-compatible iCCDS and other time-gated detectors that provide gain, robot arm compatible PMT arrays and other detectors requiring high voltage operation, detectors with improved UV and near-to-mid IR performance, near-to-mid IR detectors with reduced cooling requirements). Technologies for 1-D and 2-D raster scanning from a robot arm. Novel approaches that could help enable in situ organic compound analysis from a robot arm (e.g., ultra-miniaturized Matrix Assisted Laser Desorption-Ionization Mass Spectrometry). "Smart software" for evaluating imaging spectroscopy data sets in real-time on a planetary surface to guide rover targeting, sample selection (for missions involving sample return), and science optimization of data returned to earth. Other technologies and approaches (e.g., improved cooling methods) that could lead to lower mass, lower power, and/or improved science return from instruments used to study the elemental, chemical, and mineralogical composition of planetary materials. Improved technologies for the handling and fine manipulation of solid or powdered surface samples that could be coupled to robotic arm- or body-mounted analytical instruments.

Projects selected under this subtopic should address at least one of the above areas of interest. Multiple-area proposals are encouraged. Proposers should specifically address:

- The suitability of the technology for flight applications, e.g., mass, power, compatibility with expected shock and vibration loads, radiation environment, interplanetary vacuum, etc. Advantages of the proposed technology compared to the competition. Relevance of the technology to NASA’s planetary exploration science goals.

Phase I contracts will be expected to demonstrate feasibility, and Phase II contracts will be expected to fabricate and complete laboratory testing on an actual instrument/test article.

Sub Topics:
Visible to Far-Infrared Absolute Radiance Developments Topic T8.02
This solicitation seeks to advance the state of the art in absolute radiance measurements in the visible through the far-infrared (0.3 - 50 µm wavelength). Technologies to increase accuracy, precision, and sensitivity of absolute radiance measurements are desired. These wavelengths are of specific interest to remote sensing applications for both Earth science and planetary exploration missions.

Areas of interest include:

- Develop detector technologies to improve absolute radiance measurements in the infrared (1 - 50 µm wavelength) by increasing sensitivity, decreasing noise levels, and reducing or removing cooling requirements.
- Study and thoroughly characterize the non-linearities present in infrared detectors, specifically pyroelectric and mercury cadmium telluride (MCT), in the 5 - 50 µm wavelength region.
- Develop detector technologies to improve absolute radiance measurements in the visible to near infrared (0.3 - 8 µm wavelength).
- Develop novel compact lightweight high performance blackbody calibration source that may be enabled by recent developments in high emissivity surface treatments.
- Develop revolutionary compact, lightweight, and high performing infrared spectrometer (5 - 50 µm wavelength).

Proposals should specifically address one or more of the previously listed areas and include:

- Advantages and improvements of the proposed technology relative to current standards.
- Relevance of the technology to NASA’s science goals.
Phase II deliverables - Working prototype hardware with thorough documentation of development and complete testing and characterization results.

Sub Topics:

Navigation and Hazard Avoidance Sensor Technologies Topic T9.01
Missions to solar system bodies must meet increasingly ambitious objectives requiring highly reliable “soft landing”, “precision landing”, and “hazard avoidance” capabilities. Robotic missions to the Moon and Mars demand landing at pre-designated sites of high scientific value near hazardous terrain features, such as escarpments, craters, slopes, and rocks. Missions aimed at paving the path for colonization of the Moon and human landing on Mars need to execute onboard hazard detection and precision maneuvering to ensure safe landing near previously deployed assets. Asteroid missions require precision rendezvous, identification of the landing or sampling site location, and navigation to the highly dynamic object that may be tumbling at a fast rate. NASA seeks sensor technologies enabling these missions to solar system bodies. The same sensor or sensor component technologies can also benefit space operations such as satellite servicing and optical communication.

Sensor and sensor component technologies are sought for providing measurement of vehicle relative proximity and velocity, bearings, and high resolution 3-dimensional images during the approach to the targeted body. Also of interest are sensors capable of measuring atmospheric winds and density for aiding navigation and guidance of landing vehicles in general and large hypersonic decelerators in particular. The proposals should target advanced sensor technologies for eventual space utilization. Phase I research should demonstrate the technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from an aircraft platform or rocket-power terrestrial test vehicles. The component and sensor system technologies being sought include but limited to the following list:

- Highly sensitive Flash lidar camera including 2-D detector array, associated readout integrated circuit (ROIC), and drive/control electronics. Operational wavelength range 1.06-1.54 micron, the camera shall be capable of providing image frames greater than 60k pixels at 20 Hz with better than 5 cm range precision.
- Very compact and rugged laser transmitter operating in the 1.0 µm – 1.6 µm wavelength range with an output pulse energy of 30 mJ to 60 mJ, pulse width of about 6 nsec, and repetition rate of 20 Hz to 50 Hz suitable for flash lidars. The proposed laser must show path in maturing for operation in space environment.
- Ultra compact or micro-chip lasers generating 0.2 mJ - 2 mJ in 1.0 µm – 1.6 µm wavelength range. Laser pulse width must be less than 5 nsec and its beam quality better than 2.0 M². The laser must operate at greater than 20 Hz, preferably adjustable to over 50 Hz.
- Compact and rugged single-frequency CW laser systems operating at 1.55 micron wavelength region. Proposed lasers must be able to generate at least 5 W of power with less than 5 KHz linewidth over a tunable range of about 50 nm. Systems must be highly wavelength stable and come with full supporting electronic systems for thermal and power control. The lasers must be developed with space environment considerations and demonstrate a clear path to space.
- Non-mechanical laser beam steering devices capable of 2-axis pointing laser beams over +/- 25 degrees angle.

Sub Topics:

Information Technologies for Intelligent and Adaptive Space Robotics Topic T11.01
The objective of this subtopic is to develop information technologies that enable robots to better support space exploration. Improving robot information technology (algorithms and software) is critical to improving the capability, flexibility, and performance of future missions. In particular, the NASA “Robotics, Tele-Robotics, and Autonomous Systems” roadmap (TA04) indicates that extensive and pervasive use of robots can significantly enhance exploration missions that are progressively longer, complex, and operate with fewer ground control resources.

The performance of intelligent robots is directly linked to the quality and capability of the information technologies used to build and operate them. Thus, proposals are sought that address the following technology needs:

- Advanced robot user interfaces that facilitate distributed collaboration, geospatial data visualization, summarization and notification, performance monitoring, and physics-based simulation. This does NOT include user interfaces for direct teloperation / purely manual control, telepresence, or virtual reality. The primary objective is to enable more effective and efficient interaction with robots remotely operated with
discrete commands or supervisory control.

- Mobile robot navigation for operations in man-made (inside the International Space-Station) and unstructured environments (asteroids, Moon, Mars). Emphasis on multi-sensor data fusion, obstacle detection, and proximity ops. The primary objective is to radically and significantly increase the performance of mobile robot navigation through advanced on-board sensors, perception algorithms and software.
- Robot software architecture that supports adjustable autonomy, on-board health management and prognostics, automated data triage, data management, and data distribution (middleware). The primary objective is to facilitate the creation, extensibility and maintenance of complex robot systems.

Deliverables to NASA:

- Identify scenarios and use cases.
- Define specifications based on design trades.
- Develop concepts to address use cases.
- Build and test prototype systems.
- Perform technology demonstrations.

Sub Topics:
Computational Simulation and Engineering Topic T11.02

Computational Optimization

Proposals are solicited for developing numerical methods and tools that enable robust continuous and discrete optimization as well as uncertainty quantification for physics based computational models. There are many different optimization methods and implementations of some of these methods are available in commercial and open-source form. These methods typically use a “function call” to evaluate a performance model to be optimized. We seek proposals to develop new methods and tools for developing an integrated performance model that represents the behavior of a system (or component) by integrating multi-disciplinary performances. We are not interested in discipline-specific performance models (e.g., a FEA model of a solar panel dynamics). We are interested in model representations that capture different physical phenomena in a system (e.g., structural, dynamic, thermal, geometry, etc.). Our objective is to enable automated and/or human-in-the-loop optimization of complex, multi-disciplinary system models. We are also interested in uncertainty quantification of these models. Methods or tools that leverage discipline-specific, commercial packages that are commonly used in engineering design at NASA and other relevant fields (e.g., DoD, automotive, aerospace, etc.) are of high interest.

The integrated performance model should clearly demonstrate how it may be used to first evaluate performance against different requirements and then improved (automated or human-guided) to give an optimal performance (in a weighted sum manner) against the different requirements. Intrinsic in this is the parameterization of the discipline-specific aspects of the performance model and exposing the parameters for optimization. In Phase I, it is expected that the proposer will demonstrate integration of at least two different disciplines. One of these disciplines should be geometry via Computer Aided Design software. If successful, Phase II will mature the work-flow and develop integration with a number of different discipline specific tools. Given the maturity of discipline specific tools, we expect the TRL level at the end of Phase II to be 4-6.

Virtual Worlds

Proposals are solicited for development of computational tools that enable rapid demonstration of mission concepts. The intent of such a tool is to enable non-experts in animation to rapidly build mission scenarios and visually express their concepts in a virtual world. These tools should enable full 3-D visualization by importing of CAD parts of electromechanical systems (e.g., rovers, landers, orbiters), environment models (height field maps with textures for terrain, star maps and planetary bodies), animation functionality to show temporal progression and movement of appropriate objects in the scene. The tool should support animation of flexible bodies (e.g., solar panel vibrations) along with articulation of components. The tool should feature a ray-tracing engine for good quality visualization with shadowing, ambient lighting, etc. The tool should also be able to demonstrate terrain artifacts such as rocks, dust and ejecta as both static and dynamic objects. An example of a static artifact may be a rock pile that does not move during the animation while a dynamic artifact may be dust rising from a lander thruster interaction with terrain. Note that the emphasis is on visualization and not necessarily on the physics of the problem. However, the tool should have API for integration with physics engines (e.g., ODE, Bullet, Proprietary Code) so that physics simulations can be used to control temporal progression of a scene. There should also be a
functionality to write simple scripts for animating the virtual entities. There should be an avenue for developing a library of animation objects (e.g., rovers, terrains and locations) for re-use in later concept developments. The tools should be cross platform and enable development of animations or movies. The tool should take advantage of graphics processors or enable use of cluster computers for fast rendering of complex scenes. Alternately, the tool could feature a server-based functionality where the front-end user-interactions are through a webpage (using Java, HTML or other alternatives) and the computations are remotely conducted. Support for multiple concurrent users for content creating is desired. Ease of user interaction is key to the success of the tool. It is expected that at the end of Phase I, the performer will deliver an architecture document that captures the full intent of the tool. Similarly, performer will deliver software prototype of the implementation of the tool. It is expected that the software at the end of Phase I will be a prototype and may not have all features implemented or debugged. Performer will identify options for desired licensing options for the software to be developed for Phase II. At the end of Phase II, the performer will deliver all source code associated with the tool and verification test cases demonstrating all the proposed features within the software. The performer will also deliver a document summarizing the installation and usage of the tool and appropriate licensing options. In case of use of any third party software (e.g., open-source code) in this effort, the performer will deliver an acknowledgement that they have complied with appropriate licensing agreements. The anticipated TRL level at the end of Phase II is 5-6.

Sub Topics:

Advanced Structural Health Monitoring Topic T12.01

This subtopic seeks new and innovative technologies in structural health monitoring (SHM), integrated vehicle health management (IVHM) systems, their corresponding analysis tools, and smart materials. Advanced structural composites and sensors with the potential to enable or enhance distributed damage detection for aerospace vehicles and spacecraft are sought. Example systems should allow for detection of damage states including corrosion, electrostatic discharge, delamination, cracking, microcracking, porosity, fiber breakage, impact damage, micrometeoroid orbital debris impacts on orbit, and general material property degradation due to aging. The innovative introduction of smart aspects to composite structures, for example, autonomous healing, shape memory, or piezoelectricity, is of interest. Such structures could allow for the realization of the mass reduction that composite materials have promised for spacecraft through enhanced damage tolerance. The addition of multi-functionality would be an asset towards improving overall system efficiency.

NASA is evaluating advanced composite structures due to their relatively high strength, light weight, and potential low production cost. Currently, damage tolerance concerns require that much thicker and heavier composite structures be manufactured to compensate for potential damage, and therefore the weight savings that composites promise has not yet been achieved. Smart sensor systems and smart structural composites could address this issue of damage tolerance, thereby allowing composites to be far lighter. Development of advanced technologies is required to improve the capability to better detect damage during manufacture and lifetime. Determining the extent of damage and/or autonomous healing of damage will also reduce the complexity of composite maintenance and increase performance lifetime and reliability.

This STTR seeks to enable the creation of smart composite systems and smart sensor systems for extended structural life monitoring and/or self-repair. Primary material systems for this STTR can include metals, but it is highly desirable to target carbon composite structures. Inclusion of smart or enhanced materials such as piezoelectric, shape memory, and self-healing will be highly advantageous. Other potential sensors are: Surface Acoustic Wave (SAW)-based sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces direct-write film sensors, and others. Sensor systems can include sensors that can be applied post-manufacture of the structure. All systems will provide information about location and extent of the structural deficiency. It is not required but considered highly advantageous to directly relate to a measurable material property such as remaining material strength, density, etc.

Suitable target structures include but are not limited to primary and secondary structures, including vehicle, habitat module, and pressure vessel structures. Target structures may be relevant to either existing or future aerospace vehicles and spacecraft. SHM and IVHM systems applicable to the International Space Station are especially of interest, though the scope of the solicitation is not limited to this application. This subtopic is not intended for materials coupon-level work only; proposed systems should have a targeted demonstrator structure identified as a deliverable.

In Phase I, composite samples or prototype sensor systems will be fabricated and tested to demonstrate basic functionality of the material or sensor system. The targeted demonstrator structure will be identified, and critical test environments and associated performance predictions will be defined relative to the final operating environment. Deliverables include composite samples, sensors, associated test data, predictions, and lessons learned.
In Phase II, while full-scale demonstrators are not required, scaled-up systems will be built in application-appropriate geometries. Demonstrators will be tested in a simulated operational environment to demonstrate performance in critical areas. Further scale-up requirements will be defined, and performance predictions will be made for subsequent development phases. Deliverables will include samples and the associated test data, sensor hardware and predictions.

Sub Topics:

High Temperature Materials and Sensors for Propulsion Systems Topic T12.02

Advanced materials, structures and sensors are crosscutting technologies which are essential in the design, development and health maintenance/detection needs of components and subsystems that will be needed in future generations of aeronautics and space propulsion and power systems. Materials will require multiple or tailored functions that are designed to meet specific mission needs. Lightweight, high temperature, environmentally stable and multifunctional materials and reliable structures will be needed to meet the challenges of future aerospace systems. Improved temperature capability enables increased thermodynamic efficiency and improved performance.

- Develop innovative approaches to enhance the durability, processability, performance and reliability of advanced high temperature materials (metals, ceramics, polymers, high-strength fibers, composites, nanostructured materials and coatings to improve environmental durability.
- Develop and demonstrate hierarchical assembly of nano and microstructures to give ultra-lightweight materials with unique thermal, electrical, and/or mechanical properties.
- Multifunctional materials and structures as a means to reduce component weight.
- Physics based modeling tools that capture the modes of materials degradation in the extreme environments found in propulsion systems.

Innovative smart sensing methods and measurement techniques that can reliably assess component health in the harsh environments experienced in aerospace engines and vehicles that go beyond the limits of current sensing technology. Interest is in:

- Sensors and systems with a fast response, able to be used at high temperatures, low volume and weight, be minimally intrusive and possess high accuracy and reliability.
- Development of nano-sensor technology allowing sensors that are smaller, more energy efficient and the ability to provide more sensitive health assessments.
- Approaches to measure strain, temperature, heat flux, deflection, acoustics and/or acceleration of structural components.
- Integration of sensors into systems (wireless, wired or fiber optic).

Sub Topics:

Advanced Bladder Materials for Inflatable Habitats Topic T12.03

This subtopic solicits advanced bladder materials for use in inflatable structures. Inflatable structures are a solution for increasing the volume and decreasing the weight and launch package for habitats, airlocks, and potentially other crewed vessels. Ideal bladder materials are low permeability gas barriers, durable over time, and do not degrade due to effects such as cold flow. Low permeability bladder materials that can withstand extreme cold temperatures (-90 °F), recover, and then deploy at low temperatures (-30 °F and -50 °F) while still maintaining low permeability rates (goal of 1.5 cc/100in²/day/atm), are of particular interest. Multi-functional materials (self-healing, flame resistant, puncture resistant...) are also of interest, however, cold flexure is of prime concern. The bladder materials should also be low mass (goal of <6 oz./yd²) and be able to be manufactured into complex shapes (such as dual curvature). Developments can include material development and testing, and/or demonstration of manufacturing techniques.

Phase I and/or Phase II deliverables should include material identification and/or development, and bladder materials flexure tested at various temperatures (such as room temperature, -30 °F, and -50 °F) and then permeability tested at room temperature. In addition, bladder materials can be lightly packed and folded and then taken to even colder temperatures (for example; -90 °F, -75 °F, and/or -60 °F) for an extended period of time (24 hours to a few months), allowed to recover, unfolded at cold temperatures (-30 °F and -50 °F) and then permeability tested at room temperature. Bladder materials should demonstrate the ability to be manufactured into complex shapes. The colder temperature the bladder materials can withstand (cold storage and deployment) and
still meet the permeability goal, after recovery, the better the results.

Sub Topics:
Experimental and Analytical Technologies for Additive Manufacturing Topic T12.04
Additive manufacturing is becoming a leading method for reducing costs, increasing quality, and shortening schedules for production of innovative parts and component that were previously not possible using more traditional methods of manufacturing. In the past decade, methods such as selective laser melting (SLM) have emerged as the leading paradigm for additive manufacturing (AM) of metallic components, promising very rapid, cost-effective, and on-demand production of monolithic, lightweight, and arbitrarily intricate parts directly from a CAD file. In the push to commercialize the SLM technology, however, the modeling of the AM process and physical properties of the resulting artifact were paid little attention. As a result, commercially available systems are based largely on hand-tuned parameters determined by trial and error for a limited set of metal powders. The system operation is far from optimal or efficient, and the uncertainty in the performance of the produced component is too large. This, in turn, necessitates a long and costly certification process, especially in a highly risk-aware community such as aerospace.

State of the Art
This topic seeks technologies that close critical gaps between SOA and needed technology in both experimental and analytical areas in materials design, process modeling and material behavior prediction to reduce time and cost for materials development and process qualification for SLM.

What is the compelling need for this Subtopic?
Additive manufacturing is largely an emerging technology that shows great promise for the defense, energy, aerospace, medical and commercial sectors. Technological advancements are needed in the areas of:

- Real-time additive manufacturing process monitoring for real-time material quality assurance prediction.
- Reduced-order physics models for individual phases of additive manufacturing technique.
- Analytical tools to understand effects of process variables on materials evolution.
- Digital models to standardize the use of structured light scanning or equivalent within manufacturing processes.
- Software for high-fidelity simulation of various SLM phases for guiding the development, and enabling the subsequent verification.

The technology enabling to further utilization and certification for aerospace components. Almost all NASA Centers have capability in additive manufacturing and will benefit from this technology. This technology will accelerate growth in commercial development.

STMD/NASA/NARP/National - The subtopic is highly consistent with the technology objectives within the Strategic Space Technology Investment Plan and the NASA’s technology roadmaps. The subtopic is also closely aligned with the National Manufacturing Initiative and the Materials Genome Initiative.

Sub Topics:
Advanced Propulsion System Ground Test and Launch Technology Topic T13.01
Rocket propulsion development is enabled by rigorous ground testing to mitigate the risk inherent in spaceflight. As next generation propulsion systems are developed matching/related advancements in test technologies to appropriately test the new propulsion systems as well as more overall advancements in test technologies are also required. This subtopic area seeks to develop advanced ground test component and systems technologies to reduce cost and schedule, to improve reliability and quality, and to increase safety in Rocket Propulsion Testing. Many of these types of technologies may also have benefit for launch operations. Specific technologies of interest:

- Innovative Facility Components. Efficient generation of high temperature (>2500°F), high flowrate (<60 lb/sec) hydrogen, devices for measurement of pressure, temperature, strain and radiation in a high temperature and/or radiation environment, Development of innovative rocket test facility components (e.g., valves, flowmeters, actuators, tanks, etc.) for ultra-high pressure (>8000 psi), high flow rate (>100 lbm/sec) and cryogenic environments. Robust and reliable component designs which are oxygen compatible and can operate efficiently in high vibro-acoustic, environments.
- Advanced Test Facility Monitoring. Embedded sensor systems to provide advanced diagnostics to monitor
test facility parameters includes high-speed, simultaneous heat flux, temperature, pressure, strain and near-field acoustics. This includes remote monitoring of vacuum line, gas leaks and fire, where the use of wireless/self-powered sensors to eliminate power and data wires would be beneficial. The proposed innovative systems must lead to improved safety and reduced test costs by allowing real-time analysis of data, information, and knowledge through efficient interfaces to enable integrated awareness of the system condition by users.

- Advanced Test Imaging & Analysis. Advanced test imaging technologies providing ultra-high dynamic imaging ranges with frame rates suitable for high speed event reconstruction. The proposed innovative systems must be capable of imaging at better than 500 frames/sec, IRIG-B compatible, and with ultra-high contrast ratio. The image data must also be transferred and recorded in real time, remote from the camera optics. It must also be capable of recovering from saturated pixels from very bright objects. Ability to analyze object speed and trajectory through stereo imaging is highly desirable.

Phase I will develop feasibility studies, validate system concepts and possibly produce prototypes. Phase II will development prototype hardware and validate the technology readiness for meeting ground and launch propulsion test requirements.

Sub Topics: